A Test for Evaluating Pedal Gangrenous Lesions

Observation of Elevation Reactive Hyperemia as a Gauge of Blood Supply

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• Estimating the development of collateral circulation in peripheral vascular diseases is simplified by the use of an easy test—which can be done in an office—in which reactive hyperemia is observed in an extremity as it is gradually lowered after a period of elevation.

The lower limits of filling pressures necessary to allow spontaneous healing of necrotic lesions under the conditions described seem to be in the range 35 cm. above the heart. Similarly the lower limit for the successful performance of amputations at the level of the forefoot or toes seems to be about 45 cm.

As a result of over a thousand observations in a period of over five years, it is believed that the test provides in a few minutes a visual and reproducible picture of the filling pressures in the distal portions of the extremity which is useful in the determination of prognosis and the selection of treatment of gangrenous lesions of the foot.

THE COLOR OF THE SKIN may afford important diagnostic information in many conditions, and the factors underlying the tints and depth of color in varying circumstances are of considerable interest, not only from a purely physiological point of view but also from a clinical standpoint. The color of the skin is dependent upon the most superficial vessels—the capillary loops—and the vessels into which they drain, the subpapillary venous plexus. Thus, the normal color of the skin is produced by blood which is in or has already passed through capillaries, the arteriolo-venular bridges or the neuromyoarterial glomus. Since color alterations are the product of blood flow, direct information can be obtained regarding the circulatory status of the skin by knowledge of color changes under varying test conditions. This knowledge has been applied to the evaluation and treatment of necrotic lesions of the foot.

The distribution of blood is carried out by the great vessels and their branches, but the effective physiologic changes pertaining to the metabolism of the cell occur in the capillary bed. It is at this point that the actual interchange of nutrient and waste substances takes place, based on the relation of the colloid osmotic pressure to the capillary pressure. Death of tissue due to vascular insufficiency is incipient or takes place only in relation to the capillary. Thus it is desirable to know the adequacy of this capillary pressure in the various conditions of health and disease.

Ability to measure or evaluate capillary or small vessel pressure should give information on which to base a choice between conservative and radical procedures in the treatment of various types of necrotic lesions of the foot, regardless of the cause. Various indirect methods have been used to estimate the capillary blood pressure and the resultant computations have ranged from approximately 10 to 70 mm. of mercury in patients with essentially normal systemic pressure.[2,3,8,9] The results have varied widely and each method has had imperfections which have led to error.

Landis, in carrying out the measurement of capillary blood pressures in the hand by direct cannulation, called attention to the changes which occurred on raising and lowering the extremity.[8] He noted that elevation of the hand above the heart decreased the pressure and that lowering it increased the pressure. It has also been noted that, with the patient supine, when the lower extremity is elevated into the "L" position the blood pressure in the arteries of the thigh and leg is lower than when the leg is in the horizontal position, owing to the hydrostatic effect. The nearer the point at which measurement is made is to the foot (when the leg is elevated) the lower will be the observed pressure (Figure 1). The difference between the pressures in the brachial artery and the arteries of the thigh and leg in these different positions is approximately equal to the height of a blood column which would reach from one arterial level to the other.[7,13] There does not appear to be any major nervous mechanism in the extremity governing the caliber of the arterioles to antagonize gravity such as exists in the splanchnic area to protect the head and upper portion of the body from sudden pressure changes on positional alteration.

The appearance of color in the skin at various heights above the heart has been used as an index of capillary pressure or, more exactly, as an index of the level above the heart at which the capillary

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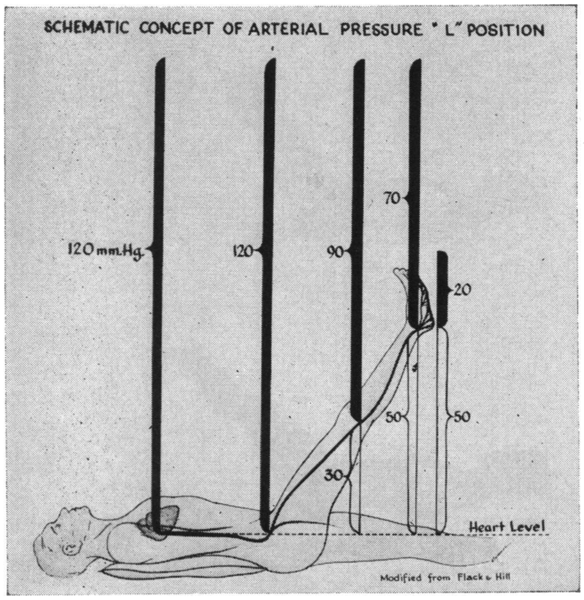

Figure 1.—Schematic concept of pressure in "L" position.

and subpapillary venous plexus have been filled. The appearance of color in the skin as reflection of blood filling the capillary or venous plexus at various heights above the heart is felt to be a reflection of the pressure in the arterial system since pressure is necessary for the elevation of fluids, in this case blood, above its source—the heart. The method to be described herein might in reality be called a quantitation of the old and well-tested "elevation pallor" maneuver.

Capillary blood pressure by micro-cannulation was found to be approximately 32 mm. of mercury in the skin of the hand when the hand is held at heart level.[8] This probably constitutes merely a pressure within a normal range, since in a normal person elevating the hands above the head is not followed by blanching of the hands. The pressure necessary on hydrostatic principles to maintain this blood in the hand held above the head would be in the range of 50 to 70 mm. of mercury or 65 to 100 cm. of blood. Inversion of the body is not followed by blanching of the feet, even in extremely tall persons. Capillary pressure thus varies widely and probably also fluctuates with changes in cardiac pressure and central pressure change in the great arteries. It is reasonable to assume that there must be a minimal pressure below which capillary pressure relations are so disturbed that failure of support of cell metabolism takes place. It is also reasonable to assume that gangrene occurs in the distal portion of the extremities with obstruction of main arterial channels due to this failure in the intraluminal capillary pressure. In clinical practice the development of local necrotic lesions of the foot as the result of circulatory failure alone is somewhat unusual. Such lesions occur more commonly when trauma (physical, chemical or thermal) is superimposed on a previously depressed circulation and, by definition, on a previously depressed capillary pressure.

It is obvious that in an attempt to quantitate capillary pressure by observation of skin color it would be desirable to eliminate the vasomotor tone as a factor, in the hope of reducing the many gradations of color. It likewise would be desirable to secure a situation in which a maximal number of capillaries are available for the filling of the subpapillary venous plexus. If the circulation to a part is arrested over a period of time and then released, the skin flushes and the volume of the part increases because the flow of blood through it is greater for a time than it was before the vessels were occluded. This so-called reactive hyperemia occurs independently of the central nervous system and has been shown to be related to the metabolic debt. Barsoum and Smirk[1] demonstrated the presence of a substance, having the biological properties of histamine, that may be the agent bringing this about. The flow of blood thus produced is as great as can be created, with the exception of that following muscular exercise.[12] Reactive hyperemia has been used to provide an adequate base-line for pressure measurements because a near maximal blood flow can be produced thereby and because of the simplicity of its application.

THE ELEVATION REACTIVE HYPEREMIA TEST

I have used a method of estimating the blood pressure in the minute vessels of the skin of the foot by a method involving elevation of the foot and observation of reactive hyperemia in the elevated position. Details of the test procedure are as follows:

With the patient in a supine position on the examining table the extremity to be studied is elevated to a standard height of 65 cm. (measured from the base of the heel to the surface of the table) and kept there for ten minutes. During this period the brachial blood pressure is noted as well as the anterioposterior diameter of the chest at the level of the fourth rib. If no blanching occurs on elevation or if cyanosis or skin pigmentation makes color determination difficult, the femoral artery is occluded by inflation of a blood pressure cuff about the thigh to above the brachial systolic level (Figure 2, A). The feet are then emptied of blood by massage until they are pallid. This pallor is maintained by inflating a pneumatic cuff, previously applied at the ankle, to a pressure greater than the systolic pressure. The cuff at the thigh is then released (Figure 2, B). The occlusion is maintained for a period of 5 to 10 minutes, the longer occlusion periods being used for cold extremities. On release of the occluding cuff,

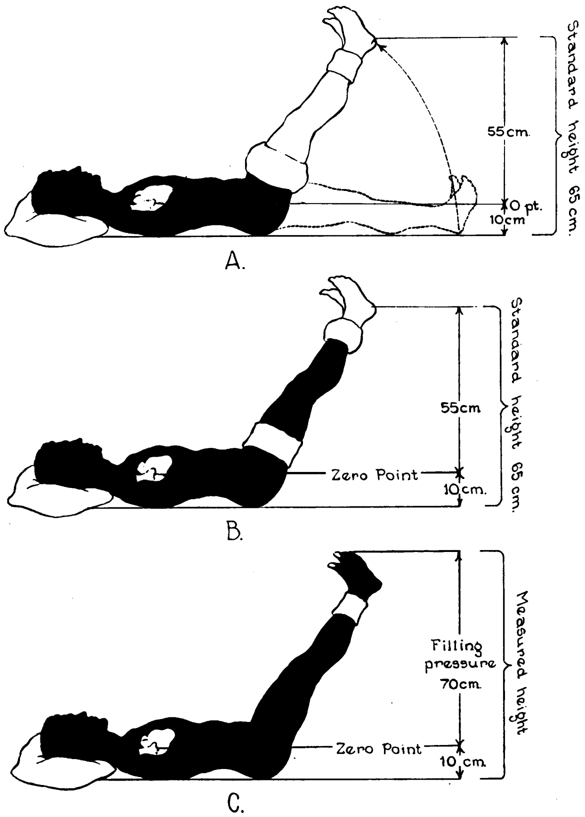

Figure 2.—Method of performance of elevation reactive hyperemia test with tourniquet.

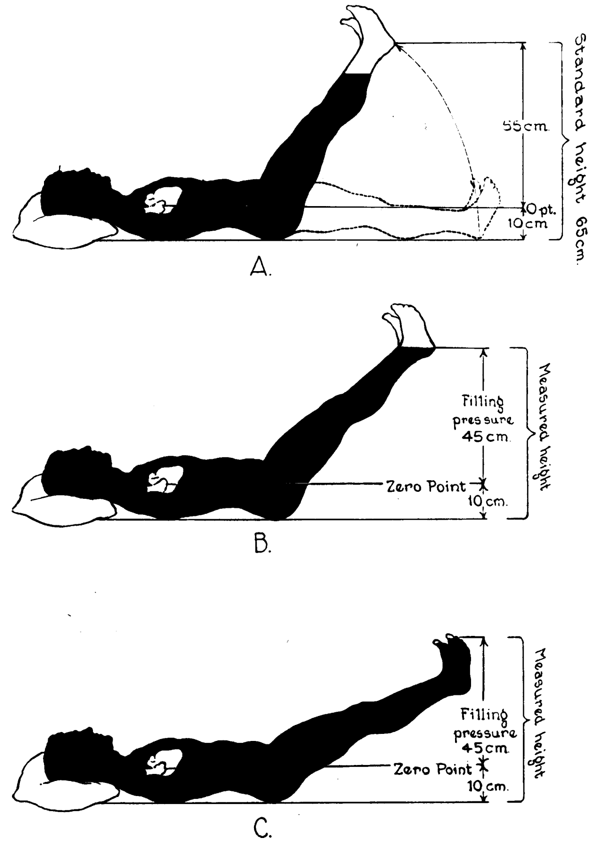

Figure 3.—Method of performance of elevation reactive hyperemia test without tourniquet.

the level to which the flush rises is measured from the surface of the table (Figure 2, C).

Many of the subjects studied with this test had lesions involving the foot, particularly the plantar area, and therefore this area was used extensively for observation. The plantar area was also used because of the reactivity of the blood vessels in this area and the maximum color changes to be seen there, probably due to the enormous number of arterial channels supplying it.

If a hyperemic flush is not observed in the part under observation, that part is lowered in 10 cm. decrements at 30-second intervals until a definite zone of hyperemia or color is seen at or about the lesion or area under consideration. The hyperemic flare customarily seen with the extremity in the horizontal or dependent position may be replaced by the appearance of a light pink or "living color" since, with the foot in the elevated position, the subpapillary venous plexus, which is largely responsible for the hyperemic color of the skin, is rapidly drained.

In cases in which there is spontaneous and complete blanching on elevation, the occluding cuff is not used, the stimulus to reactive hyperemia being provided by only a 10-minute period of elevation followed by lowering in the previously described fashion (Figure 3).

The level of the right heart halfway through the chest at the 4th rib is used as a zero point or baseline. The anteroposterior diameter of the chest is measured at the level of the 4th rib with an x-ray centimeter scale. One-half of this measurement is subtracted from the measured height—that is, the height from the surface of the table to the top of the hyperemic flush (Figure 2, C and Figure 3, B and C). This measurement is considered to be approximately the pressure, in centimeters of blood above the right auricle, necessary to fill that area. This measurement, or height of color return above the right heart, has been termed the *filling pressure* or *height of penetration of cutaneous hyperemia.*

The determinations are carried out under artificial light, since this seems to enhance the red color upon which the measurement depends.

In normal controls, the entire distal portion of the extremity will fill in a maximum of 45 seconds and in most cases in less than 15 seconds. A similar filling or flushing time exists in patients with vasoconstrictive disease who have cold, pale, wet cyanotic feet.

TABLE 1.—*Fluctuations in Filling Pressure Related to Changes in Brachial Blood Pressure*

Case No.	Lesion	Blood Pressure (Brachial) in Mm. Mercury	Filling Pressure Height in Cm.	Brachial Blood Pressure Change Due To	Blood Pressure (Brachial) in Mm. Mercury	Filling Pressure Height in Cm.
1.	Occlusion, femoral artery	240/145	87+	Hypertensive heart disease and cardiac failure	160/100	35
2.	Occlusion, femoral artery	260/110	90+	Hypotensive drugs	160/60	35
3.	Arteriosclerosis of aorta and branches	160/100	75+	Coronary occlusion, cardiac failure	100/60	10
4.	Occlusion, iliac artery	180/90	85+	Arteriosclerotic heart disease, cardiac failure	110/70	30

Performance of this test is also useful for delineation of obliteration of small vessels, such as digital arteries, distal to the main arterial trunks. These small local areas of decreased blood supply can be easily mapped out during the performance of this test. Blanching of these areas and subsequent flushing following the lowering of the part indicates that the area has a decreased or failing blood supply as compared with the rest of the foot.

USE OF TEST IN PROGNOSIS OF GANGRENOUS LESIONS

In a series of more than a thousand observations, 150 were carried out on patients who had necrotic or gangrenous lesions of the foot and leg. There were 41 cases of amputation at the level of the toes or the forefoot in which studies were carried out preoperatively. The patients were studied carefully by the usual clinical methods, including oscillometry, arteriography, reflex vasodilatation tests, sympathetic nerve block, peripheral nerve block and biopsy, as well as by general clinical and laboratory evaluations. A detailed study of 90 observations was previously reported, as well as a careful evaluation of 33 patients who had amputations at the level of the forefoot or toes.[5,11]

In this test, relatively long periods of ischemia or arterial occlusion are used, because it has been demonstrated that the time necessary to produce maximal blood flow following arterial occlusion is greater in the lower extremity than Scheinberg and co-workers reported was necessary in the upper extremity.[14] Pertinent also is the observation by Greenwood and co-workers[6] that longer occlusion is necessary to produce visible hyperemia when the part is elevated than when horizontal.

The test is designed to be carried out at ordinary room temperatures with the occlusion being provided by an ordinary sphygmomanometer cuff. Table 1 shows the fluctuation in the filling pressure that can occur with changing blood pressures as measured by auscultation at the brachial artery. Thus comparison of filling pressure or height of penetration of hyperemia from day to day necessarily must include registration of the brachial arterial pressure. There seems to be a filling pressure or height of penetration of cutaneous hyperemia, as estimated by this method, below which necrotic lesions of the foot do not heal. This height or level approximates 35 cm. above the heart level. Secondarily it was noted that primary union or rapid secondary healing of amputations occurred in all cases in which there was penetration of hyperemia to 45 cm. or more at the amputation site. In several cases in which low filling pressures or low penetration of cutaneous hyperemia was accompanied by progressive death of tissue, healing began upon restoration of arterial continuity and an increase of filling pressure. Data on a case in point are given in Table 2.

On many occasions it was observed that although the foot filled at a height well above the required 35 cm., dependent rubor or pronounced reactive hyperemia developed with the limb in the dependent position following bed rest with the leg and foot at heart level. This led to conjecture that effective nutrition might not coincide with filling pressures of 35 to 45 cm.

In an attempt to find out the level at which nutrition was effective, approximately 50 microcuries of I^{131} in buffered solution making up a total volume of 1.125 ml. was inserted into the corium of the skin of the foot with a No. 30 hypodermic needle. Just before the insertion of the iodine, the sole of the foot was blanched either by occlusion of the femoral artery or by elevation alone and the ischemia was maintained by blood pressure cuff inflated to 300 mm. of mercury at the ankle. Immediately following the insertion of the iodine into the skin of the foot, a scintillation counter was positioned against the sole or dorsum of the foot and counts were recorded for not less than 5 minutes or more than 10 minutes. It was noted that the iodine remained where it had been placed so long as the occluding cuff was in place. Following deflation of the

TABLE 2.—*Progress in an Extremity in Which Low Filling Pressure Was Accompanied by Gangrene of First Right Toe*

Lesion	Height of Penetration of Hyperemia (Cm.)	Result
Arteriosclerotic obstruction of femoral artery; gangrene first right toe	0	Progression of lesion
Treatment	**Postoperative Height of Penetration of Hyperemia (Cm.)**	**Result**
Femoral thromboendarterectomy	45	Amputation of toe and primary union
Course	**Height of Penetration of Hyperemia (Cm.)**	**Result**
Re-thrombosis of femoral artery at 6 months	0	Recurrence of gangrene in stump

cuff the test was carried out in the usual manner and at the same time counts were made with the scintillation counter as the extremity was gradually lowered. Six patients were so studied and it was noted that the I^{131} was not removed significantly until levels of 45 cm. or more below the maximal filling pressure were reached. Similarly, in previous studies on three patients with the use of histamine diphosphate, it was observed that a histamine wheal could not be produced until the part had been depressed approximately 60 cm. below the maximal filling pressure or height of penetration of cutaneous hyperemia.

These studies indicated that perhaps filling pressures of 45 to 60 cm. are necessary for certain capillary functions. Neither of these studies, that with histamine or that with radioactive iodine, was sufficient either in number of tests or in detail to permit analysis; they merely indicate the direction of further investigation of this type in the study of capillary function in patients with obstructive or functional arterial disease. Appearance of the hyperemic flush was also checked against the increase in volume as the first blood entered the digit, using the Burch-Winsor digital plethysmograph. The two methods agreed quite closely.

Sympathetic paralysis, as produced by sympathectomy, lumbar sympathetic nerve block or peripheral nerve block, in most instances brings about a definite increase in the filling pressure.[10] To produce such a result the pressure in the more proximal larger vessels would necessarily be elevated. Blood pressure studies carried out at the ankle and wrist showed a definite rise following sympathetic paralysis, substantiating the findings of the elevation reactive hyperemia test in this regard.[4]

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